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Project Title: Science for prevention: predicting Great Lakes invasions

Project Category: Exotic Species

Rank by Organization (if applicable): 0

Total Funding Requested ($): 187,283 **Project Duration:** 2 Years

Abstract:

The addition of nonindigenous species (NIS) constitutes the largest and probably the most permanent environmental change in each of the Laurentian Great Lakes. Nevertheless, much of the scientific research on NIS has remained reactive, e.g., testing impact of already established species. In this project, we will examine earlier stages of invasions to help redirect attention on prevention of NIS invasions. Specifically, we will build on our successful research on fish invasions in the Great Lakes to develop statistical models to predict future invaders belonging to other taxonomic groups: zooplankton, macrophytes, molluscs, and phytoplankton. As for fishes, we will use Discriminant Analysis (DA) and Categorical Analysis & Regression Trees (CART) to answer the following four questions: 1) Can species that have colonized the Great Lakes from the Illinois River (or vice-versa) be distinguished (on the basis of life history and/or tolerance variables) from those species that have not done so? 2) Can NIS that successfully established in the Great Lakes be distinguished from those that were released but failed to establish? 3) Can NIS that have become invasive (spread widely from the site of introduction) be distinguished from those that have remained localized? 4) Can NIS that have high environmental impact be distinguished from those that do not? We will then use the statistical models to conduct quantitative risk assessments on species native to the Ponto-Caspian basin that may constitute future invaders. As far as is known to us, the models we have completed on fishes and those proposed here for other taxa will be the only quantitative risk assessment tools available to guide the management of NIS in freshwater ecosystems. Results will apply to all the Great Lakes, and the general methods developed will be applicable to aquatic and terrestrial taxa anywhere.

Geographic Areas Affected by the Project

States:
- [x] Illinois
- [x] Indiana
- [x] Michigan
- [x] Minnesota
- [x] New York
- [x] Pennsylvania
- [x] Wisconsin
- [x] Ohio

Lakes:
- [ ] Superior
- [ ] Huron
- [ ] Michigan
- [ ] Erie
- [ ] Ontario
- [x] All Lakes

Geographic Initiatives:
- [ ] Greater Chicago
- [ ] NE Ohio
- [ ] NW Indiana
- [ ] SE Michigan
- [ ] Lake St. Clair

Primary Affected Area of Concern: Not Applicable

Other Affected Areas of Concern:

For Habitat Projects Only:

Primary Affected Biodiversity Investment Area: Not Applicable

Other Affected Biodiversity Investment Areas:

Problem Statement:

The addition of nonindigenous species (NIS) and the consequent loss or reduction of native species constitute the largest and probably the most permanent environmental changes in each of the Laurentian Great Lakes and other freshwater ecosystems worldwide (Kolar & Lodge in press, Lodge in press, Sala et al. 2000). The most important vectors for these species introductions are increasingly well documented. A probable rank order of importance of different vectors for fishes follows: authorized stocking; canals; anglers/bait buckets; aquarists; aquaculture; and ballast water. The rank order for other taxonomic groups is less well known, but ballast water and sediments would no doubt be relatively more important for many taxa (Claudi & Leach 2000). Despite the increasing recognition of the scope, ecological changes, and economic costs that come with NIS invasions, much of the scientific research has remained reactive, e.g., testing impact of or possible control measures for already established species (Lodge et al. 1998, Kolar & Lodge in prep). That is, the research has focused most on transition 5 in Figure 1. Unfortunately, for most established NIS, extermination is impossible, control is unlikely, and even mitigation is usually expensive and difficult. We propose research on the earlier stages of invasions to help redirect attention on prevention of NIS invasions (Fig. 1).

Figure 1. Transitions that any nonindigenous species (NIS) may experience. Each arrow represents both a transition (with an associated probability) and a decision point for natural resource managers. Biological research has tended to focus on transition 5. This past focus is important, but needs to be augmented to better inform natural resources management and prevention of NIS. We therefore propose research focused on transitions 1, 2, 3, and 4.

Region of origin---(1)---> Transport---(2)---> Survival in transport---(3)--->
Establishment---(4)--->Spread---(5)--->Ecological & economic impact

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Specifically, we will build on our successful on-going work on fish invasions in the Great Lakes to develop statistical models to predict future invaders to the Great Lakes in other taxonomic groups: zooplankton, macrophytes, molluscs, and phytoplankton. By identifying native species elsewhere in the world (and their likely vectors) that represent a high risk of invasion and/or impact in the Laurentian Great Lakes, we will provide specific targets on which to focus efforts by policy makers and prevention by natural resource managers.

For zooplankton, macrophytes, molluscs, and phytoplankton, we will answer four questions, which we have already answered in on-going research on fishes:

1) Can species that have colonized the Great Lakes from the Illinois River (or vice-versa) be distinguished (on the basis of life history and/or tolerance variables) from those species that have not done so? (The Chicago-area canals connect the Great Lakes to the Mississippi drainage via the Illinois River.) This question addresses transitions 1-3 (combined) (Fig. 1).

2) Can NIS that successfully established in the Great Lakes be distinguished from those that were released but failed to establish? This question addresses transition 3 (Fig. 1).

3) Can NIS that have become invasive (spread widely from the site of introduction) be distinguished from those that have remained localized? This question addresses transition 4 (Fig. 1).

4) Can NIS that have high environmental impact be distinguished from those that do not? This question addresses transition 5 (Fig. 1).

Proposed Work Outcome:

Background and general approach: ongoing research on predicting fish invaders

Under the auspices of a National Sea Grant project nearing completion, we have adapted statistical approaches developed by ecologists studying terrestrial plant invasions (Reichard & Hamilton 1997) to categorize fish species based on 13 life history characteristics and seven environmental tolerances. The statistical tools evaluated and/or used include ANOVA, Discriminant Analysis (DA), logistical regression (LR), Categorical Analysis and Regression Trees (CART). After accumulating a comprehensive data set on all fish species in the Great Lakes and in the upper Illinois River, we asked the four questions stated above (Problem Statement section).

For fishes, the answer to all four questions is "yes," with a remarkably high degree of confidence. For example, we used DA to identify suites of characteristics that best discriminated between categories of species, derived bootstrap classification rates, and then validated the best model by using a jack knife procedure (which best simulates classification rates for species extraneous to the data set, or new to the Great Lakes). Overall (bootstrap) correct classification rates for the four questions ranged from 84% to 97% (Table 1).

Table 1. Results of statistical modeling of Great Lakes fish invasions. The four rows correspond to the four questions asked in this research. Overall classification rates refer to bootstrap results, while the remaining rates refer to jack knife results, which best simulate results for testing species not currently in the data set (=future invaders). Correct positive refer to species correctly classified as having invaded; correct negative refers to species correctly classified as not having invaded, etc. Numbers in parentheses are numbers of species in each category.

	Overall classification success (bootstrap)	Jack knife classification rates: Correct positive	Correct negative	False positive	False negative
1. Invasion via canals (9) vs. not (79)	89%	-	-	-	-
2. Successful (25) vs. unsuccessful (15)	85	84	87	13	16
3. Spread (16) vs. localized (8)	97	75	75	25	25
4. Impact (11) vs. no impact (16)	84	75	75	25	25

For each question, only 3-4 variables were needed to make correct classifications, which is encouraging for the application of these results. This also suggests that results could be used immediately to shape policy and management decisions. For example, for question 1, the 9 species misclassified as canal-users share key characteristics with species that have dispersed through the canal. Thus, the misclassified species, including bighead carp (Hypophthalmichthys nobilis), are high risk species for future dispersal via the canals. Monitoring, education, or management plans could be developed to prevent that. These results have been presented (e.g., American Fisheries Society 1999, and the ANS meeting 1999), and will be submitted for publication within a few months. One manuscript invited by Trends in Ecology & Evolution will be submitted this month.

Proposed work

Make predictions with fish models and make models available to users

With the Sea Grant-funded development of methods on fishes behind us, we are now in a position to use EPA support to take another three essential steps toward application of these results. First, we will gather data from literature sources on fish species native to the Ponto-Caspian biogeographic region and other potential source regions, and run those fishes through our models to make species-specific risk assessments for these potential invaders. Second, we will put our statistical models in simple decision tree formats so that they will be readily useable by policy makers, fisheries personnel, other natural resource managers, and personnel from relevant industries including the shipping, bait, aquaculture, aquarist and watergarden industries. Third, after submitting technical papers for peer review, we will publish user-friendly model formats in outlets read by these different constituencies (bulletins, newsletters, trade magazines, etc), as we have done for related projects (two articles on crayfish introductions in press at Fisheries).

Extending approach developed for fishes to other taxonomic groups

We will also apply the statistical approaches developed with fishes to other taxonomic groups whose members have invaded the Great Lakes previously. Specifically, we will answer the four questions described above for zooplankton, macrophytes, molluscs, and phytoplankton. For each of these four taxonomic groups, we will first collect published data on life history and environmental tolerances for native species and exotic species that are established in the upper Illinois River system, the Great Lakes, and the St. Lawrence River. We will include the St. Lawrence because many NIS exist there that have not yet invaded the Great Lakes proper (de Lafontaine et al. 2000). We will collect parallel data for NIS that have not established but that have been reported from ballast (=putative failed invaders), and species native to the Ponto-Caspian that have not been reported in North America (Table 2).

Table 2. A representative sample of data sources on life history characteristics and environmental tolerances of zooplankton, macrophytes, molluscs, and phytoplankton.

Illinois River & Great Lakes

Daniel Schneider, James Stoeckel, personal contacts routinely sampling river; Zooplankton of the Great Lakes (1984); Phytoplankton & zooplankton composition, abundance, and distribution: Lakes Erie, Huron, and Michigan, USEPA 905/3-85-003. A catalog of Illinois algae, 1944; The algae of Illinois, 1952; Distribution checklist and status of Illinois freshwater mussels (Mollusca: Unionacea), 1995; Field Guide to Freshwater Mussels of the Midwest, Illinois Natural History Survey, 1997; A survey of problematic aquatic macrophytes in Illinois, 1984, Proceedings of Illinois conf. on lake and watershed management; Aquatic plants of Illinois, IL St. Mus. Pop. Sci. Ser. Vol VI; Michigan Flora: A guide to the identification and occurrence of the native and naturalized seed-plants of the state, Part I Gymnosperms and Monocots. I, 1972; A field guide to the valuable underwater aquatic plants of the Great Lakes, UWFWS Ext. Bulletin E-1902, 1986; A guide to freshwater mollusks of the Laurentain Great Lakes with special emphasis on the genus Pisidium. EPA-600/3-80-068, 1980; Phytoplankton composition and abundance in southern Lake Huron, 1980; Phytoplankton assemblages as indicators of water quality in the Laurentian Great Lakes, 1978;

Ponto-Caspian Basin

Inventory of the Baltic Sea Alien Species, internet; Limnofauna Europea, The Caspian fauna of the Azov-Black Sea basin. Izd-vo AN SSSR. 286pp

Implications for policy & management of NIS

As far as is known to us, the models we have completed on fishes and those proposed here for other taxa are the only rigorous and quantitative risk assessment tools becoming available to guide the management of NIS in freshwater ecosystems. The high rates of correct classifications in these analyses (Table 1) bode well for successful applications in the development of policy and natural resource management strategies. They are a dramatic improvement over the exclusively qualitative and anecdotal information previously available to guide management.

Results will be directly applicable to species-specific evaluations of intentional importations for stocking or for use in aquaculture, the bait trade, or watergardens. Species-specific management is exactly what is needed for these vectors. For ballast introductions and range expansion through canals, such species-specific models will be one prong of a necessarily multi-pronged attack. Such models will be very useful to identify high risk species that could become the targets of dispersal surveillance (e.g., through the Chicago canals) or ballast monitoring programs. In addition, when shipping or other vectors shift to new areas of the world, such models would be in place to screen the native species of those new regions to assess the changing degree of risk as world trade patterns shift. Furthermore, the results will apply broadly to all the Great Lakes, and the general methods developed will be applicable in future to other aquatic and terrestrial taxa anywhere.

References cited

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Sala, O.E., F.S. Chapin, III, J.J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, E. Huber-Sannwald, L. Huenneke, R.B. Jackson, A. Kinzig, R. Leemans, D.M. Lodge, H.A. Mooney, M. Oesterheld, N.L. Poff, M.T. Sykes, B.H. Walker, M. Walker, and D.H. Wall. 2000. Biodiversity scenarios for the year 2100. Science (in press).

Project Milestones:	**Dates:**
Project Start	07/2000
Manager-friendly fish decision trees	09/2000
Zooplankton--complete models & predict	01/2001
Submit zooplankton manuscripts	04/2001
Macrophytes--complete models & predict	09/2001
Submit macrophyte manuscripts	11/2001
Complete phytoplankton & molluscs	04/2002
Submit phyto & mollusc, Project End	06/2002

☐ Project Addresses Environmental Justice

If So, Description of How:

☒ Project Addresses Education/Outreach

If So, Description of How:

We will make every effort during this project to communicate methods and results so that they are accessible to front-line natural resource managers and policy makers. For example, we will develop statistical models as decision trees that can be easily used by anyone with little or no training. We will attend meetings (NALMS, Midwest Fish & WIldlife, ANS) and write for outlets (Fisheries, LakeLine, Dreissena!, etc) that reach these same people. These efforts will be made so that the applicability of research results are realized by those in positions to use the results.

Project Budget:

	Federal Share Requested ($)	Applicant's Share ($)
Personnel:	86,188	47,790
Fringe:	14,790	0
Travel:	14,568	0
Equipment:	6,000	0
Supplies:	6,120	0
Contracts:	0	0
Construction:	0	0
Other:	0	0
Total Direct Costs:	127,666	47,790
Indirect Costs:	59,617	0
Total:	187,283	47,790
Projected Income:	0	0

Funding by Other Organizations (Names, Amounts, Description of Commitments):

This project is part of a larger risk assessment effort on the transport and introduction of nonindigenous species in the Great Lakes. The general approach and specific methods of statistical model construction have been developed under the auspices of a National Sea Grant project focused entirely on Great Lakes fishes. That project will end in summer 2000, and GLNPO funding will allow the immediate extension of this highly successful project to other important nonindigenous taxa in the Great Lakes. The stipend (about $32,000 over 2 years) and tuition ($47,790 over 2 years) for the graduate student who will work on this project, John Drake, will be paid entirely by the University of Notre Dame, under the auspices of a Schmitt Fellowship and tuition remission already awarded to Drake. Thus, UND will be contributing between $47,790 and $79,000 to this project over 2 years, depending on what proportion of Drake's time is devoted to the project. EPA funding (this proposal) would primarily support a postdoctoral fellow, Cindy Kolar.

A proposal will be submitted requesting approximately $360,000 over 3 years from the Great Lakes Restoration Act (deadline 1 March 2000) and Great Lakes Fishery Commission (deadline 4 May 2000) to apply the theory of Population Viability Analysis (developed for endangered species) to estimate how the probability of establishment is related to the population size and identity of organisms in ballast water, ballast sediments, and fouling communities. Discussions toward this end have included Marg Dochoda, Chris Wiley, and Philip Jenkins. In addition, I will be submitting a proposal on 1 March 2000 to NSF's Biocomplexity program to focus an interdisciplinary group (including biologists, philosophers, economists) on integrating the various components of risk assessment for Great Lakes NIS. These coordinated efforts will advance prevention of NIS, and especially the development of standards for ballast water effluents.

Description of Collaboration/Community Based Support:

See Education/Outreach and Other Sources of Funding sections